

Condition Based Maintenance in the Pharmaceutical Products Industry
Some Cost Related Benefits

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Abstract: At the 1996 Technology Showcase Conference, a method for assessing the cost effectiveness of condition based maintenance (CBM) was presented for the case of a batch process plant pump operation utilising a simple mathematical model. More recently, the model has been extended to permit evaluation of fans and also gearboxes which attract consequential costs due to there being no stand-by facilities when failure occurs. In this paper, the results of a study are presented and discussed as a means for determining the extent to which the cost prediction model can be utilised to establish the viability of pursuing a condition based maintenance strategy for batch type process plant machinery operation.

Keywords: Batch process plant; condition based maintenance; condition monitoring; cost benefit analysis; fans; gearboxes.

Introduction: Condition monitoring, as an aid to targeting maintenance effort has long been recognised as potentially cost effective. Consequently, condition based maintenance (CBM) has been advocated by some as the answer to reducing maintenance costs to an acceptable level in today's highly competitive industrial society. However, the economic arguments have tended to be based primarily on cost analyses which were based on continuously running, high power, high capital cost plant. In fact, there are large sections of industry which function in a batch process environment, in which the economic factors are more difficult to determine and sustain. Nevertheless, if the population of machines is sufficiently large, an economic case may be possible for the successful utilisation of CBM.

In the 1966 Technology Showcase Conference, a simple mathematical model for assessing the cost effectiveness of CBM in batch process plant was presented for the case of pumps in which no consequential costs were involved because of there being stand-by facilities available in case of pump failure (1). The model has subsequently been extended to accommodate the effect of consequential costs which are incurred, for instance, when fans fail (2). Also, the effects of the probability of detection of the onset of failure using CBM and machinery reliability have been incorporated into the revised model.

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In this paper, the results of a recent study involving gearbox performance and maintenance are presented, in which the cost savings associated with direct repair costs are related to the capital cost of the equipment by means of a non-dimensional factor (K_d), and the savings in consequential costs by a separate cost factor (K_c), both of which are related directly to the input power of the machines.

Maintenance strategy for gearboxes: The maintenance of gearboxes in the plant require a different strategy to that employed, for example, with pumps and fans. The reason for this becomes self-evident in the light of consequential costs associated with their failure, as illustrated in Fig.1, which is based on the analysis of a range of individual gearboxes located on plant. It also reveals that the costs incurred is not a direct function of the power transmitted.

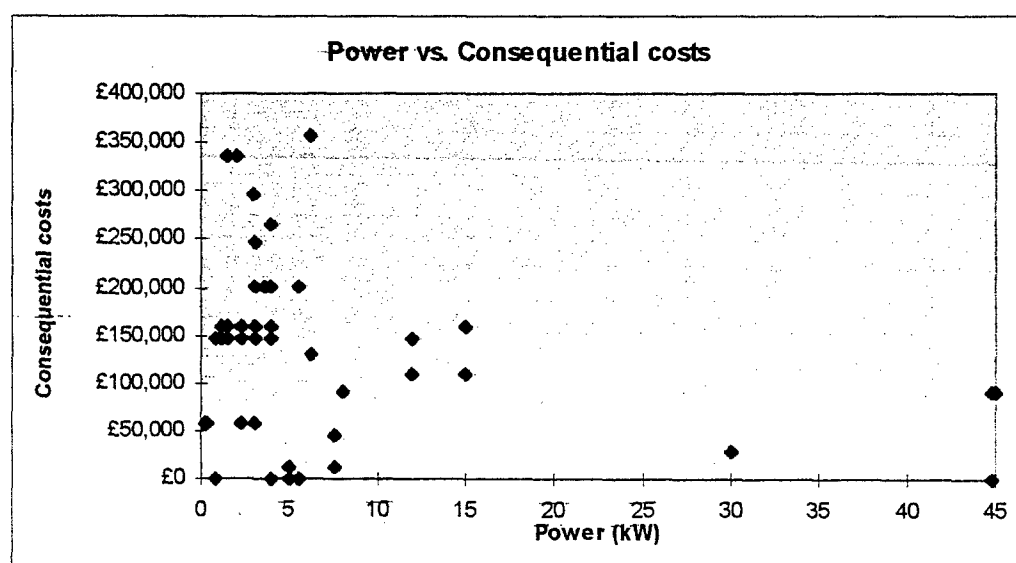


Figure 1 - Consequential costs versus power

Direct duplication or provision of 'On-the-shelf' spares will not remedy the situation in the majority of cases since the gearboxes are located on reactor vessels and dryers in which their failure leads to the production batch being lost due to the reaction being effectively out of control. To deal with this type of situation requires that the systems used must be 'fault tolerant'; i.e., the gearboxes are grossly over-designed for the particular duty so that even if a failure condition develops, the gearbox will continue to function until a 'time-window' can be found to carry out the necessary repairs. The few occasions where gear tooth failures have occurred are associated with phosphor-bronze worm-wheel type reduction gearboxes in which considerable wear and misalignment can be tolerated before complete failure occurs.

The use of condition monitoring techniques has to be considered very carefully for gearboxes operating under these conditions. Higher power gearboxes (>150 kW) are routinely monitored using oil analysis. This is done primarily to sentence the oil rather than detect incipient failure. Vibration analysis is utilised with gearboxes which attract high direct repair costs simply to minimise the damage within the box before repairs are effected.

To summarise: Whereas, in the main, consequential costs are minimised by over engineering the product, there is a price to be paid in a much higher level of capital cost incurred.

Analysis of direct and consequential costs: This analysis is based on a sample of 87 gearboxes across the plant. The total population of gearboxes is 398. Over a 5 year period there were 74 failures of these gearboxes and hence,

$$\text{Failure rate } \lambda = \frac{74}{5 \times 87} = 0.17$$

and, assuming that the failure distribution is Poisson,

$$\text{Reliability } R_t = e^{-\lambda} = e^{(-0.17)} = 0.844 \quad (1)$$

Direct costs of gearbox failure were acquired using the same method as for fans and pumps. These have been analysed using the same model as for fans and pumps i.e.

$$C_d = C_c \cdot I_p \cdot I_c \cdot I_{pr} \cdot K_d$$

where, C_d = Direct repair costs

C_c = Capital cost of gearbox

I_p = Power index

I_c = Criticality index

I_{pr} = Process index

K_d = Direct costs factor

The relationship between K_d and power was found to be of the form:

$$y = 34.54 \cdot e^{-0.0053x} \quad (2)$$

In terms of the relationship between repair costs and power, there is considerable scatter below 50 kW, nevertheless, a linear fit is obtained of the form:

$$y = 24.60x + 1018 \quad (3)$$

With regard to consequential costs the relationship is of the form:

$$C_q = C_c \cdot I_p \cdot I_c \cdot I_{pr} \cdot K_c$$

where, C_q = Consequential costs

K_c = Consequential costs factor

Again, from inspection of the data it was evident that there was considerable scatter and that it was better to divide the data into two distinct power ranges, ≤ 15 kW and >15 kW, as shown in Figures 2 and 3, respectively.

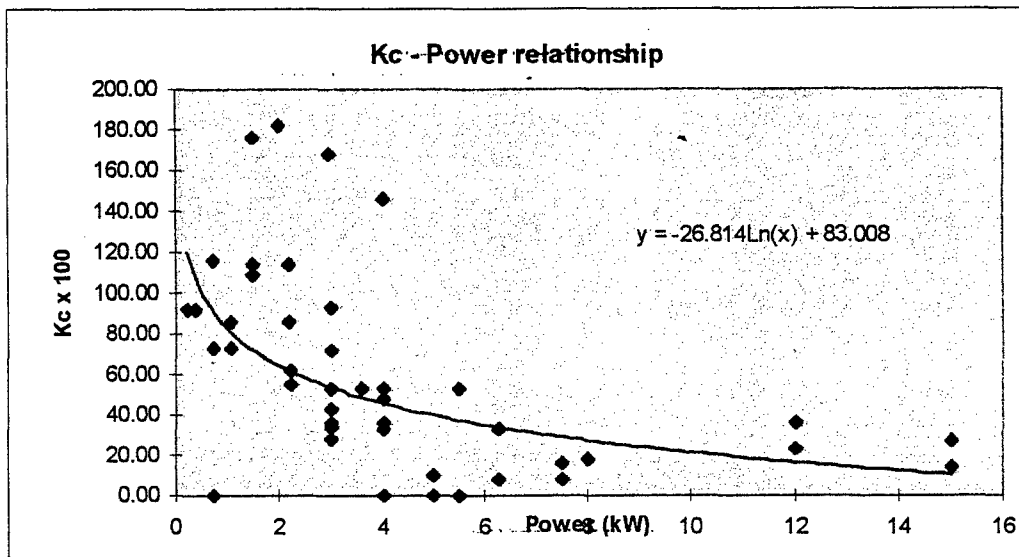


Figure 2 - Consequential costs factor, K_c versus Power (< 15 kW)

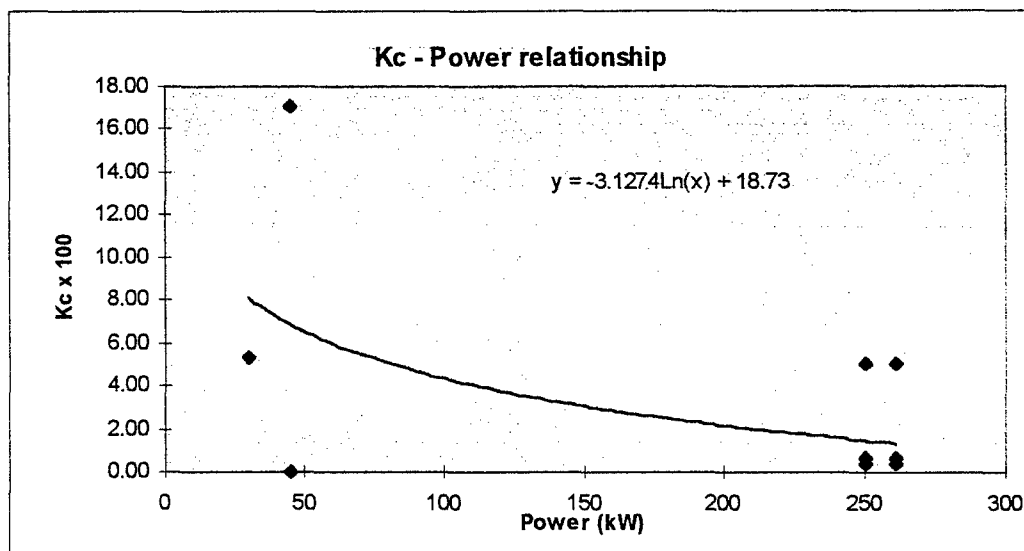


Figure 3 - Consequential costs factor, K_c versus Power (>15 kW)

Testing the model: Three gearboxes, which had not been included in the study, were selected and their direct and consequential costs ascertained and compared with those predicted using the above relationships. The gearbox details are presented in Table 1 below.

Table 1 - Gearbox details

Class of	Machine	Corrected	Direct	Consequential	Power	Criticality	Process
Machine	Description	Cost*	Costs*	Costs*	Index	Index	Index
Gearbox	Gbox 'A'	£2,442	£222	£159,512	1	10	9
Gearbox	Gbox 'B'	£3,519	£1,852	£45,530	2	10	4
Gearbox	Gbox 'C'	£5,345	£1,652	£28,542	5	10	2

(*) These figures are in pounds sterling, as is also the case in Tables 2 and 3 below.

The formulae tested were:

- 1) Direct costs as predicted by $K_d = 34.541e^{-0.0063(Power)}$ and $C_d = C_c * I_p * I_c * I_{pr} * K_d$
- 2) Direct costs as predicted by $C_d = 24.595(Power) + 1017.9$
- 3) Consequential costs as predicted by $K_c = 83.008 - 26.814Ln(Power)$
(For gearboxes with input power <15 kW)
 $K_c = 18.73 - 3.1274Ln(Power)$
(For gearboxes with input power >15 kW)

The results based on the predictions are listed in Tables 2 and 3 below:

Table 2 - Direct costs

Machine description	Predicted direct costs (1)	Predicted direct costs (2)	% difference (1)	% difference (2)
Gearbox 'A'	754	1,045	240	370
Gearbox 'B'	927	1,202	-50	-35
Gearbox 'C'	1,528	1,756	-7.5	6.2

Table 3 - Consequential costs

Machine description	Predicted Consequential costs	% difference
Gearbox 'A'	176,845	11
Gearbox 'B'	81,578	79
Gearbox 'C'	43,260	52

Clearly, the agreement at low powers is not good, but improves considerably at higher powers.

Concluding remarks: The purpose in developing the model is to provide management and engineers on plant with appropriate means to decide whether the employment of condition monitoring methods as part of a condition based maintenance strategy is a viable prospect. It is evident that a simple mathematical model can be used to predict the direct and consequential costs of machinery failure with a reasonable degree of confidence, although it is also apparent that some refinements are necessary to improve the prediction, especially for lower power units. By using the results it is possible to set up a decision making system to evaluate the cost effectiveness of different maintenance regimes, along similar lines to the method described in references (1) and (2). As was found in the previous analyses of pumps and fans, an essential element of the decision making process is the reliability of the machinery class involved and the probability of detection using machinery health monitoring techniques. Consequential costs outweigh all other considerations and, therefore, some form of condition based maintenance is the most effective way of dealing with the problem.

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